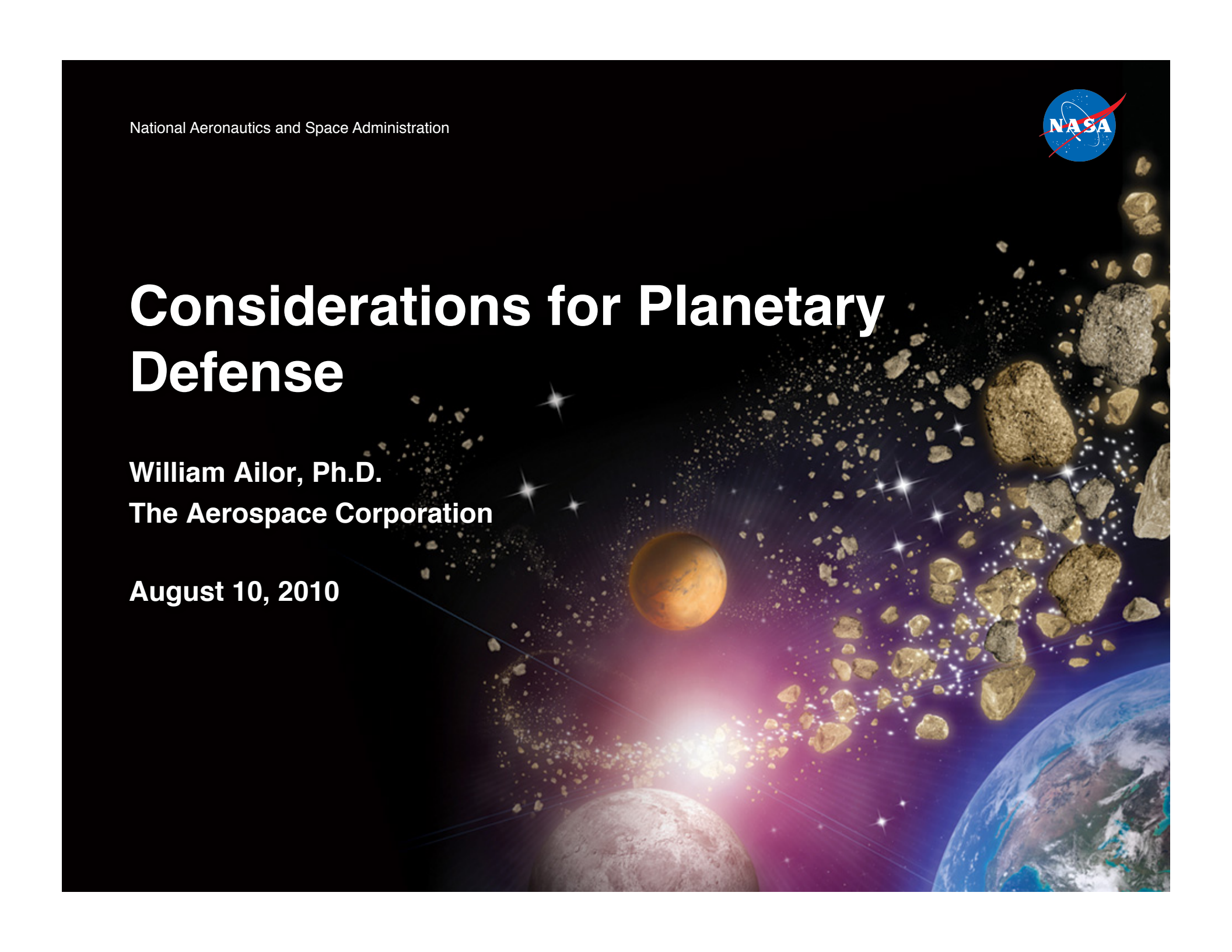
National Aeronautics and Space Administration



Considerations for Planetary Defense

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Planetary Defense: Objectives & Requirements

Detect and verify NEO threat as far away from Earth as possible

Move threatening NEOs to non-threatening orbits

Requirements:

- Perform comprehensive search and survey for potential threats
- Precise tracking & orbit predictions to assure threat is real as far ahead of potential impact as possible (minimize false alarms)
- Means to apply force to approaching NEO sufficient to reduce probability of impact below acceptable limit
- Verification that mitigation attempt worked

Why a human?

- Risk reduction—need to know as much as possible about nature of NEOs and how a threatening object might respond to a mitigation attempt
  - Need to understand small forces that affect tracking (e.g., Yarkovsky); understand how mitigation attempt might change those forces
  - Need to understand how activities might affect attached sensors and hardware (e.g., Lunar dust)
  - Need to reduce uncertainty for slow push, impulsive mitigation techniques
  - Carefully designed and executed experiments can provide answers
  - Need to understand NEO physical properties including local properties, global properties, and variations among NEO populations
- Human mission expands experiment options, mission success
  - Multiple experiments using multiple protocols at multiple locations during same mission
- Human observation and involvement provides insights on the unexpected
  - Insights derived addressing problems increase understanding (e.g., dust on lenses, dust on visors, attachment problems)
  - Data from multiple sensors could improve knowledge of structure, composition, response to mitigation attempt (e.g., seismic info from explosion or impact test)

Tracking & Orbit Determination

- Accurate tracking essential for assessing threat, verifying mitigation success
  - Impact predictions affected by thermal re-radiation effects (Yarkovsky)
  - Yarkovsky effects depend on NEO characteristics: bulk density, size, thermal conductivity, rotation rate, rotation pole direction
- Options for improving tracking
  - Landed transponder or reflector
    - Requires landing/attachment system
    - Solar power and communications possibly limited by asteroid rotation
    - NEO environment (dust) might affect performance
  - Information from spacecraft orbiting or station keeping nearby
    - Images and data also help determine NEO shape, mass, rotation rate, bulk density, existence of companion “moon”
    - Could be essential for verifying success of mitigation mission
- Options for improved orbit prediction
  - Information on object’s size, shape, rotation rate, rotation pole direction, mass
  - Thermal conductivity

Move an Object: Slow Push Techniques

- Attach rocket motor, mass driver, other device to the surface to “push” NEO
- Use gravitational attraction between nearby spacecraft to “pull” NEO to new orbit (Gravity Tractor)
- Shine laser or solar energy on surface to impart small force
- Apply force over period of weeks to months
- Requires
  - Info on mass, shape, dynamics
  - Interacting with surface or operating in close proximity for long periods
  - Confidence that attachment; precise orbit/station-keeping control of Gravity Tractor; laser or solar interaction will work as planned
  - Accurate tracking to know when mission successful; possibly target subsequent attempts

Move and Object: Impulsive Techniques

- Impact NEO with projectile at very high relative velocity (Kinetic Impact; e.g., Deep Impact mission)
- Detonate explosive device above, on, or below the surface of the NEO
- Requires
  - NEO mass
  - NEO type (rubble pile, solid body)
  - NEO composition (iron, rock, etc.) & properties
  - Accurate tracking post event to verify success, target subsequent attempts

Human Mission: Objectives for Planetary Defense #1

Gather data, test techniques for improving threat prediction, mitigation verification

- Test & characterize techniques for attaching transponders, other devices to NEO
- Test technology required for long-term station-keeping and orbiting a NEO
- Collect detailed information on shape, size, mass, bulk density, thermal properties, rotation
- Leave capability to verify effectiveness of mitigation techniques (e.g., observer spacecraft)

Human Mission: Objectives for Planetary Defense #2

- Measure mass properties, begin database of physical characteristics to narrow uncertainty (homogeneity, etc.)
- Test and characterize mining concepts
- Observe effects of laser impingement, focused solar on NEO surface
- Assess effect of human activities on NEO environment (e.g., will dust coat tracking reflectors, affect transponder performance?)
- Develop model of NEO's gravitational field for development and testing of station-keeping concepts

Human Mission: Objectives for Planetary Defense #3

- Return samples of NEO and compare bulk density of samples with bulk density of NEO to estimate porosity (useful for mitigation)
- Design spacecraft to maintain close station with NEO (verify thrusters don't impinge, active control system and sensors function as required)
- Observe (with remote spacecraft) kinetic impact and measure effect
- Coordinate in-depth human exploration with broad robotic surveys